BRIEF DESCRIPTION OF THE DRAWINGS

FIG. 1 is a perspective diagram of an example of three-terminal filter using the conventional area expansion vibration mode.

FIG. 2 is a circuit diagram of three-terminal filter shown in Fig. 1.

FIG. 3 is a perspective diagram of an example of three-terminal filter according to a preferred embodiment of the present invention.

FIG. 4 is a sectional view of three-terminal filter shown in Fig. 3.

FIG. 5 is a diagram showing the polarization direction of the three-terminal filter shown in Fig. 3.

FIG. 6 is a diagram of the three-terminal filter of Fig. 3 using the area flexural vibration mode.

FIG. 7 is a filter characteristic view of the three-terminal filter shown in Fig. 3.

FIG. 8 is a diagram showing the relationship of the thickness and the length of one side of a three- terminal filter using the area flexural vibration mode and a three-terminal filter using the area expansion vibration mode.

DETAILED DESCRIPTION OF PREFERRED EMBODIMENTS

Fig. 3 and Fig. 4 illustrate a first preferred embodiment of the three-terminal filter using the area flexural vibration mode according to the present invention.

This filter A preferably includes two piezoelectric layers (piezoelectric ceramics layers) 1 and 2 having a substantially square shape that are laminated with an internal electrode 3 interposed therebetween. Surface electrodes 4 and 5 are respectively provided on exterior main surfaces of the laminated piezoelectric layers 1 and 2. The thickness of both of piezoelectric layers 1 and 2 is preferably approximately the same.

The internal electrode 3 is connected to a ground terminal 3a, one surface electrode 4 is connected to an input-terminal 4a, and another surface electrode 5 is connected to an output-terminal 5a. A circuit diagram is illustrated in Fig. 2.

The piezoelectric layers 1 and 2 can be polarized in the same thickness direction as shown in Fig. 5A, in opposite outward-facing directions as shown in Fig. 5B, and in opposite inward-facing direction as shown in Fig. 5C.

For example, as shown in Fig. 5B, in the filter A including piezoelectric layers 1 and 2 which are polarized in opposite directions, when a positive potential is applied to the input-terminal 4a and a negative potential is applied to the output-terminal 5a, the electric-field E is produced in a direction extending from the surface electrode 4 to the surface electrode 5.

The piezoelectric layer 1, in which the polarization direction is opposite to the electric field direction, expands in the direction of the flat surface. The piezoelectric layer 2, in which the polarization direction is the same as the electric field direction, contracts in the direction of the flat surface. Therefore, as shown in Fig. 6, the filter A bends to become upwardly convex. If the direction of an electric field is reversed, the filter A bends to become downwardly convex. Therefore, if a high-frequency electric field is applied between the input-terminal 4a and the output-terminal 5a, the filter A vibrates in an area flexural mode at a desired frequency.

Fig. 7 shows the amplitude characteristics and the group-delay property (GDT) in the filter A according to the first preferred embodiment of the present invention.

As clearly shown from Fig. 7, outstanding filter properties are produced with the filter A.

In a resonator using the area expansion vibration mode, a resonance frequency is determined by only the length of the side, and is not affected by the thickness of the resonator. On the other hand, in a resonator using the area flexural vibration mode, the resonance frequency Fr is determined by the thickness t and the side length L according to the following formula:

$$Fr \propto t/L^2$$

Thus, the resonance frequency Fr is proportional to the thickness t and inversely proportional to the square of the length of the side L.

In Fig. 8, the element size in the same frequency (Fr=40kHz) of the filter A using the area flexural vibration mode and the resonator using the area expansion vibration mode is compared.

As illustrated in the diagram, at the identical frequency, an element vibrating in an area flexural mode is approximately 1/5 smaller than an element vibrating in an area expansion mode. Particularly, in the Fr=40kHz three-terminal filter, the length of one side is about 50 mm in an area expansion mode vibrating element. However, in an area flexural mode vibrating element, the length of one side is about 10 mm or less. Also, if the thickness of an area flexural mode vibrating element is about 0.2 mm or less, the side length of the element is reduced to about 5 mm or less.

Thus, according to preferred embodiments of the present invention, a three-terminal filter including the three electrodes and the two piezoelectric layers are alternately laminated and the piezoelectric layers are polarized in the thickness direction, wherein one surface electrode functions as an input electrode, another surface electrode functions as an output electrode, and an internal electrode functions as a ground electrode. Therefore, the two piezoelectric layers produce an area flexural vibration mode. Thus, the size of filter according to preferred embodiments of the present invention is greatly reduced compared to a filter using an area expansion vibration mode or a filter using a length vibration mode having the same frequency. Conversely, where the filters are the same size, a three-terminal filter having a lower frequency is obtained according to preferred embodiments of the present invention.

Moreover, since the frequency can be adjusted by the changing the thickness and the side length, the three-terminal filter having various frequencies can be obtained.

While the present invention has been described with reference to what are at present considered to be preferred embodiments, it is to be understood that various changes and modifications may be made thereto without departing from the invention in its broader aspects and therefore, it is intended that the appended claims cover all such changes and modifications as fall within the true